

INFRASTRUCTURE AND SOCIOECONOMIC CHARACTERISTICS OF SMALL AIRPORTS WITH REGULAR COMMERCIAL AVIATION SERVICES ON THIN-DEMAND ROUTES OPERATED BY LOW-CAPACITY AIRCRAFT

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Abstract. The existing literature on the aviation market has focused more on analysing high-capacity airports served by larger aircraft, often overlooking smaller airports that operate low-capacity planes on routes with low demand. This study examines Azul Conecta's operations in Brazil using Cessna Grand Caravan aircraft, focusing on the key features of the airports served by this niche service. It applies k-means clustering to 189 airports in Brazil and examines the characteristics of the services they provide. It aims to fill the knowledge gap regarding the characteristics of airports used in this niche market. The findings indicate that airport characteristics associated with the presence of flight service, including socioeconomic variables, are typically associated with regular commercial aviation, whereas infrastructure characteristics are identified as differentiation factors in airports with more limited resources.

Keywords: air transport, general aviation, infrastructure, small airport business, regional aviation.

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1. Introduction

Small airports provide access to remote areas, and the air transport industry has a significant impact on the local economy, both by supporting other sectors and through its own activities (Dimitriou & Sartzetaki, 2018). Simultaneously, routes connecting remote airports are more vulnerable and rely heavily on incentive policies (Fageda et al., 2019), often served by only one airline due to lower demand. Thus, this study aims to deepen the understanding of the characteristics of these airports and the routes they serve to ensure continuity in air transport capillarity.

There is no universally accepted standard, either regulatory or research-based, for classifying a regional airport, particularly about thresholds for air traffic movements (ATMs), passenger throughput, or other metrics. Furthermore, studies on the factors influencing air traffic at small airports, using regression analysis, tend to have lower explanatory power (Dziedzic et al., 2020) compared to those involving larger metropolitan areas, which adds complexity to the analysis of these infrastructures. The challenges and the diverse range of definitions for the term “regional airport” are highlighted through a systematic literature review by Pauwels et al. (2024).

Similarly, airlines specifically designed to serve the regional market, targeting smaller airports and operating aircraft with lower seat capacities, receive less attention in the literature, which often focuses on comparisons between Low-Cost Carriers (LCCs) and Full-Service Carriers (FSCs). When the term “regional airline” appears in the literature, it typically refers to carriers operating regional jets and turboprop aircraft with seating for around 70 or more passengers (Tomová & Materna, 2018; Sedláčková & Tomová, 2021), being Fageda and Flores-Fillol (2012), with a wider range of aircraft types, an exception. The literature review reveals a lack of studies analyzing operations involving aircraft that transport 30 passengers or fewer, the upper threshold for a Federal Aviation Administration [FAA] Part 135 type of service (FAA, 2024).

This paper examines the case of Azul Conecta, a regional subsidiary of Azul Airlines in Brazil, which is the only national airline to operate aircraft with limited seating capacity under the RBAC 135 scope nationwide (National Civil Aviation Agency, 2023). The study observes the characteristics of small airports that accommodate this type of flight service. To address the difficulties in defining regional airlines and airports, the case study applies a filter to isolate the targeted service type. Airport infrastructure

characteristics, such as runway pavement and VFR/IFR capabilities, serve as differentiators for the market niche studied, while consolidated variables, such as population correlation, depend on the type of service provided. The findings presented herein aim to assist policymakers and aerodrome operators in assessing whether their infrastructure possesses the potential for regular commercial service, thereby potentially justifying the necessary investments to attain the desired level of national connectivity.

This study is divided into five sections. The literature review for aircraft types and small airports is presented, followed by the case study presentations and respective results and conclusions.

2. Aircraft types in regional services

It is observed that the airports discussed in the literature mostly handle commercial flights using narrow-body turbofan jet engines, such as the Boeing 737 and Airbus A320 models, along with their respective variants, which are designated by aircraft codes 3C or 4C, in accordance with International Civil Aviation Organization [ICAO] standards (ICAO, 2022). These aircraft typically seat between 150 and 220 passengers. In studies focused on American low-cost carriers (LCCs), for example, it is noted that neither Southwest Airlines nor JetBlue has formed partnerships with regional airlines, unlike other major players such as American Airlines, Delta, United, and Alaska (Tomová & Materna, 2018). Southwest Airlines operates exclusively with Boeing 737 aircraft (Boguslaski et al., 2004). Although JetBlue has a more diverse fleet, it is increasingly focusing

on Airbus aircraft, with both the A220 and A320 variants gaining ground, following an initial reliance on Embraer E190 models, which were more prominent at the start of its operations (Müller et al., 2012).

The accessibility of air transport services in the United States underscores the importance of regional aviation within the route network. In 2017, regional carriers accounted for nearly 19% of all domestic enplanements, with load factors ranging from 70% to 83% (Tomová & Materna, 2018). Simultaneously, the typical partnership model between major and regional airlines is not commonly seen worldwide and varies significantly from arrangements in other regions. In the U.S., both low-cost airlines, such as Southwest and JetBlue, and major airlines partnering with regional carriers maintain relatively high traffic volumes and frequent flights on routes with thinner demand, which are typically served by these regional carriers. Generally, the term regional aircraft refers to models such as the Canadair Regional Jet CRJ-100/200/700/900 and the Embraer E135/145 and E170/175 series (Tomová & Materna, 2018). The seating capacity of those aircraft far exceeds that considered in this study, as available in Table 1.

A notable exception in terms of the range of aircraft types is the study by Fageda and Flores-Fillol (2012) on the optimal distribution of traffic for network airlines. In this study, using the route networks and aircraft fleets of American and European FSCs, the impacts of regional jet technology and the low-cost business model for serving thin routes out of main hubs are evaluated. The study finds that regional jets are more commonly used on shorter routes with a high percentage of business travelers. It also notes that turboprop aircraft are mainly used on routes

Table 1. Narrow-body Turboprop, regional jet, and mainline jet typical seating capacities (source: Airbus, 2024; ATR, 2023; Boeing, 2024; Embraer, 2024)

Type of Aircraft	Model	ICAO code	Typical seating
Turboprop	ATR 42	AT42	42–48
	ATR 72	AT72	72
	British Aerospace ATP	ATP	64
	De Havilland DHC-8-100/200	DH8A / DH8B	37–40
	De Havilland DHC-8-300/400	DH8C / DH8D	50–56 / 82–90
	Embraer 120	E120	30
	Fairchild Dornier 328	D328	30–33
	Fokker 50	F50	46–56
	Saab 340/2000	SF34	30–36
Regional jet	Avro RJ 70/85/100	RJ70/RJ90/RJ1H	70–94 / 112 / 122
	Canadair Jet CRJ-100/200/700	CRJ1/CRJ2/CRJ7	50 / 50 / 66–78
	Canadair Jet CRJ-900/1000	CRJ9/CRJX	81–90 / 97–104
	Embraer RJ 135/140/145	E135/E140/E145	37 / 44 / 50
	Embraer RJ 170/175	E170/E175	70–78 / 78–88
	Embraer RJ 190/195	E190/E195	96–114 / 108–124
	Fokker 70	F70	72–85
	Fokker 100	F100	97–122
Mainline jet	Airbus A318/319	A318 / A319	107–132 / 124–156
	Airbus A320/321	A320 / A321	150–186 / 185–230
	Boeing 717-200	B712	106–117
	Boeing 737-700/800	B737 / B738	128–149 / 160–189
	Boeing 757-200/300	B752 / B753	200–239 / 243–295
	MD 80/90	MD80 / MD90	117–155 / 141–172

shorter than 300 miles and, to a lesser extent, on routes between 300 and 600 miles. Regarding the business model, the study shows that on longer routes with leisure travelers, a low-cost subsidiary is advantageous. More detailed information about the aircraft types included in Fageda and Flores-Fillol's (2012) sample, which covers nearly all the relevant aircraft discussed in the literature, is provided in Table 1.

As shown in Table 1, the typical minimum seating capacity in the route network literature is 30 seats, with turboprop aircraft ranging from 30 to 90 seats. Meanwhile, regional jets typically seat 50 to 124 passengers. Although the study encompasses a wide range of operations, it overlooks the niche market of aircraft with fewer than 30 seats, where models such as the Cessna Grand Caravan (C208) and Beechcraft 1900 (B190) are commonly used.

Therefore, the apparent discrepancy in aircraft capacities indicates an opportunity to address a gap in the literature and gain a better understanding of the regular commercial operation of lower-capacity aircraft. The economics of flights with fewer passenger seats available is challenging and often tied to the company's network strategy, as shown by Tomová and Materna (2018) in the United States, and by Oliveira and Oliveira (2022) for Azul's case in the Brazilian context.

Although challenging, the possibility of operating low-demand routes with aircraft such as Cessna Grand Caravan, commonly configured to a capacity of between 9 and 12 passengers, and Beechcraft 1900, with up to 19 seats, would have the potential to greatly expand the number of airports with regular commercial service and increase air transport capillarity.

3. Small airports

The literature suggests that route development activities vary by airport size, with smaller airports less likely to attend route development networking events or meet with airlines in their offices. It is believed that low-traffic infrastructure has more limited resources and expertise for route development (Halpern & Graham, 2016). Furthermore, these airports also tend to have a naturally smaller market and, as a result, limited potential to increase demand for their services, which would not justify greater efforts in active route development. It is expected that smaller airports will be more reliant on subsidies or external influence to attract or maintain air service. According to Fageda et al. (2019), routes linking remote airports are more vulnerable and dependent on incentive policies, often being served by only one airline due to the relatively lower demand.

Studies on airport choice factors for such low-demand markets are limited. Research on small airports accounts for a relatively small portion of available studies, and the terms used to describe these structures are often vague and vary among authors. Terms like "regional", "remote", "rural", and "small" are frequently used interchangeably (Iyer & Thomas, 2021). Subsidies are commonly used to

promote routes to remote or isolated regions, and although those terms are often used interchangeably, the accessibility challenges they face differ. Remote locations are far from cities with more infrastructure, but some land access is provided. On the other hand, isolated communities do not have this basic type of access available for certain periods or year-round (Silva et al., 2022).

Although the number of studies examining the commercial services of smaller airports is limited, there is no consistent way to define the lower and upper size limits for airport classifications. In a study of small European airports, Dzedzic et al. (2020) categorize airports as "small" if they handle up to 1 million passengers annually. In that sample, many of the airports included have fewer than 200,000 passengers per year, although this threshold may be considered high depending on the research scope.

From an economic perspective, the costs associated with operating and maintaining smaller airports, along with mandatory investments to meet regulatory requirements, are relatively high. In summary, small airports often face limited traffic, fixed infrastructure costs, and insufficient revenues to cover their expenses (Cioaca et al., 2019). The operational costs of small aerodromes are of public interest, as most are run by local governments, which means taxpayers' money is involved.

Not only should the attraction of new regular service be pursued, but also its long-term continuity and reliability. According to Stone (2016), in a study conducted in a small U.S. city that receives regular commercial air service, reliability is among the most essential factors in air travel choice for small communities, cited by more than 40% of respondents. Although some details of the respondents' answers are provided, the study does not delve further into the determinants of air transportation reliability.

In another context, Dobruszkes et al. (2017) examine the trend of hybridization through a case study of airports serving the city of Barcelona, where Girona Airport, located outside the metropolitan area, lost significant traffic to Barcelona Airport. In this study, airports are not categorized by traffic volume, instead, the metropolitan area size (in terms of population) is used to classify airports into different categories. The lowest threshold includes airports serving areas with fewer than 250,000 inhabitants.

Therefore, using terms like "small airport" or "regional airport" does not ensure that the literature findings are directly related or applicable to the scope of this research. In the Brazilian Regulator (ANAC) categorization of airports with regular commercial service, the lowest level is "Classe I," which corresponds to passenger volume below 200,000 annual passengers. International organizations also lack a unified definition of airport size. FAA generally categorizes airports depending on their share of passenger in a national level, being a "Small Hub" an airport with a share between 0.05% and 0.25% of total U.S. enplanements. Using FAA available definitions (FAA, 2025), airports within the scope of this study would be categorized as "Nonprimary Commercial Service", with scheduled passenger service and between 2,500 and 10,000 enplanements, or as general

aviation airports, defined as those with no schedule service or with less than 2,500 passenger boardings. EASA and other international associations, such as IATA and ICAO, do not have a similar categorization to a level that allows for strict differentiation of the scope of this study.

The FAA definition of “general aviation” airport is not adopted to avoid any doubt about the subject studied, as the research is focused on regular commercial aviation service. Thus, given the lack of consensus at the national level or within international organizations, to limit the study’s scope, it will be based on regulatory thresholds that set a higher standard worldwide. For example, although not identical, ANAC’s RBAC 135 scope (National Civil Aviation Agency, 2022) and FAA Part 135 (FAA, 2021) encompass a similar type of service and aircraft.

Small airports often exhibit characteristics similar to those of general aviation dedicated aerodromes (Silva et al., 2022), and are often limited by infrastructure, competition, or regulatory restrictions on receiving regular commercial flights. At the same time, even studies that address the “airport choice” in lower-demand situations often use passenger volume thresholds ranging from hundreds of thousands to millions, figures not comparable to the niche market here, which lies between general aviation traffic and regular commercial service commonly studied in the literature.

In the context of this study, as explored in the next section, a filter based on the type of operation is applied, and the focus is on the “spokes,” or peripheral cities, in the airline network. Considering the scope of the market niche studied, the maximum passenger output of airports characterized as small in this study is limited to 10,000 passengers per year, which translates to a maximum of around 10 weekly flights using Cessna Grand Caravan aircraft at full passenger capacity, according to its certification in Brazil.

4. Case study

Based on potential gaps identified in the literature review, since research in the passenger air transport sector mainly focuses on larger structures and does not address the niche of thin routes served by aircraft with low seat capacity, the topic of airport characteristics operating under those thin demand conditions is established.

Passenger air transportation serving small airports and utilizing smaller aircraft is often associated with subsidized routes due to the inherent lack of economies of scale for this type of service, which would otherwise be insufficient to attract airline interest. This case study does not explore if subsidies are directly related to the services provided, focusing on, given the existing context, understanding the factors associated with the airport selection of thin-demand routes.

Subsidies are typically used to promote routes to “remote” or “isolated” regions, and although these terms are often used interchangeably, the accessibility challenges they face differ. Remote locations are far from cities with

better infrastructure, but some land access remains available. Conversely, isolated communities lack this basic type of access entirely or only have it during certain times of the year (Silva et al., 2022). Given these characteristics, it is expected that remote and isolated locations will be present in the dataset.

For this study, the thin demand market is defined as regular commercial air service operating under the scope of RBAC 135, Amendment 13 (National Civil Aviation Agency, 2023), which concerns public air transport in aircraft with a maximum seating capacity of 19 passengers and a maximum payload of 3,400 kg.

Aerodromes eligible for this study are spread across the country, leading to diverse geographic and demographic characteristics. Selected low-demand routes span various states in Brazil, each with distinct regional characteristics. Initially, 3,463 aerodromes were identified in the National Civil Aviation Agency (2024) database. The filters applied in steps 1 to 5 helped narrow down the study’s scope, as shown in Table 2.

Firstly, the database is reduced to public airports capable of receiving commercial flights. Secondly, some airports were interdicted or had operational restrictions at the time of the study and were thus also discarded from the dataset. Later, as the incentives to RBAC 135 scope flights are applied at the state level in the Brazilian context, only airports located within those states are maintained. In step 4, the dataset is limited to airports with no commercial flights under the RBAC 121 scope (aircraft with more than 19 seats), to remove locations with higher demand and flights operated by aircraft such as AT72, A320, and B737. Lastly, secondary airports at the state capital were removed, as in the states analyzed only the capital’s main aerodrome is used for commercial flights, and the values of variables such as population for those locations would contaminate the rest of the dataset.

At the time of the study, routes within the Amazon region were observed, whereas São Paulo, the most populous state in the country, was not present. Most routes connected cities within the same state, except for services between a nearby state capital and smaller cities

Table 2. Filters applied to the database

Step	Number of aerodromes before	Filter applied	Number of aerodromes after
1	3,463	Only public airports	503
2	503	Operational airports (not interdicted)	458
3	458	Only airports within states served with routes under RBAC 135 scope	236
4	236	Airports not receiving regular commercial aviation under RBAC 121 scope	193
5	193	No secondary airports located in the state’s capital	189



Figure 1. Airport sample and routes served

in another state. Subsidized routes served the states of Amazonas (AM), Ceará (CE), Espírito Santo (ES), Maranhão (MA), Mato Grosso (MT), Minas Gerais (MG), Pará (PA), Paraná (PR), Paraíba (PB), Pernambuco (PE), Rio Grande do Norte (RN) and Rio Grande do Sul (RS). The locations of the airports in the final dataset and the existing routes are shown in Figure 1.

In Brazil, most thin-demand route operations occur in states where roads connect the cities served, except in Amazonas and Pará, where air transport competes with other modes. Silva et al. (2022) use cluster analysis, including data from other South American countries and other continents, to classify subsidized routes based on their common characteristics.

Considering the vastness of Brazilian territory and the resulting diversity of regions where the selected aerodromes are located, a clustering mechanism is applied to the data. Clustering groups data objects into different clusters so that the data within each cluster is similar but

distinct from other groups (Zalik, 2008). It can also be used to discover potential hidden patterns in datasets. For the clustering process, geographical features such as latitude, longitude, and connectivity are utilized to segment the data, identify the characteristics of the routes served, and determine whether they serve economic or lifeline purposes, as per the division adopted by Silva et al. (2022).

To analyze the data from this study, the k-means clustering algorithm (MacQueen, 1967) was employed. The algorithm divides the input dataset into k clusters, each represented by a centroid that adapts over time. It calculates the squared distances between data points and their respective cluster centers, assigning each data point to the cluster center closest to it. For clustering N data points x_1, x_2, \dots, x_n into k distinct subsets $C_i, i = 1, \dots, k$, the algorithm minimizes the mean-square-error (MSE) cost function given by Equation (1).

$$J_{MSE} = \sum_{i=1}^k \sum_{x_t \in C_i} \|x_t - C_i\|^2, \quad (1)$$

where: x_t is a vector representing the t -th data point in the cluster C_i ; C_i is the geometric centroid of the cluster C_i ; $\|x_t - c_i\|^2$ is a chosen distance measurement between data point x_t and the cluster center C_i .

The k-means algorithm assigns a data point x_t to the i th cluster if the cluster membership function $l(x_t, i)$ is 1.

One characteristic of the k-means algorithm is the need to specify the number of clusters in advance. In Figures 2 and 3, plots of different methods for determining the optimal number of clusters in the dataset are shown: the Elbow Method, the Silhouette Method, and the Gap Statistic Method. Those can be divided into direct methods (Elbow and Silhouette) and statistical testing methods (Gap Statistic).

In the Elbow Method, the location of a bend in the plot is generally considered an indicator of the appropriate number of clusters. As it looks at the total Within Sum of

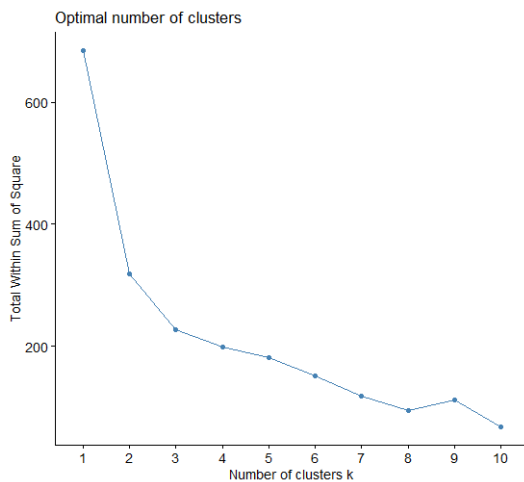


Figure 2. The Elbow Method

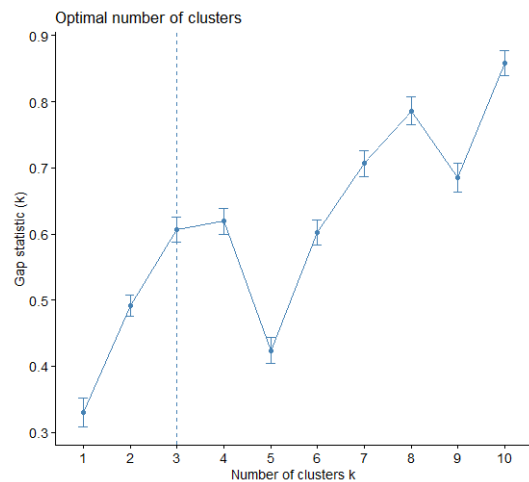


Figure 3. Gap Statistic method

Squares (WSS) as a function of the number of clusters, the number of clusters would be chosen so that adding another cluster does not significantly improve the total WSS.

This study adopts a statistical method to compare the total intra-cluster variation of different values of k with their expected values under the null reference distribution of the data, considering the proposal by Tibshirani et al. (2001). When the gap statistic is maximized, the clustering structure is far from the uniform distribution of the data.

As shown in Figure 3, the sum of squares decreases significantly when four or more clusters are formed; beyond that point, the benefit of increasing the number of clusters diminishes. In Figure 3, the Gap Statistic method identifies three as the optimal number of clusters. Given the convergence of the optimal number of clusters across the processes, the dataset will be divided into three groups.

Figures 4 and 5 show the results of data clustering. A Principal Component Analysis (PC) demonstrates the clustering for $K=2$ and 3 values for data visualization purposes.

When the data is divided into three clusters, using the variables AMZ (if located in the Amazon Area), CONEC (road connectivity), LAT (latitude), and LON (longitude), as presented in Table 3, the distribution of each group is as follows:

- Aerodromes in the Amazon area (Amazonas, Pará, Mato Grosso, and Maranhão states airports);
- Aerodromes in Minas Gerais, Espírito Santo, and northeast states (Ceará, Pernambuco, Paraíba, and Rio Grande do Norte);
- Aerodromes in the south region (Paraná and Rio Grande do Sul states).

After data segmentation based on the clusters in Figure 4, the characteristics of the routes served in each cluster are analyzed to categorize airports by service type. Most thin-demand route operations identified in this study occur in states where roads connect the cities served, meaning that air transport competes with other modes.

In Silva et al. (2022) cluster analysis, which included countries from South America and other continents, subsidized routes were classified based on common characteristics, with the lack of road connection serving as a differentiator for the type of service provided. Examining the case study data shows that routes within the Amazon region (k -group 1) qualify as “lifelines” for isolated areas, indicating that passenger air transportation remains the sole dependable and available means of transport. On the other hand, the routes of both other k -groups can be classified as economically driven, meaning that factors commonly found in the literature for flight service generally apply.

The thin-demand routes in Brazil, focused in this study, are commonly related to state-level incentives, predominantly in the form of fuel tax reductions, to encourage increased airline services and to facilitate business or tourism travelers seeking more time-efficient transportation. This is exemplified by the incentives implemented by the state of Paraná (Diário Oficial do Estado do Paraná [DOE], 2019). In the Brazilian market, Azul Conecta, a subsidiary of Azul Airlines, uses Cessna Grand Caravan aircraft (see Figure 6) to connect state capitals primarily with smaller regional and remote airports across the country, with some focus cities serving as origins or destinations for these routes.

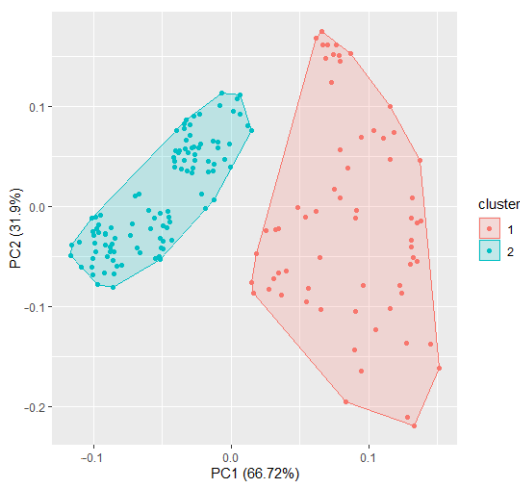


Figure 4. Data is divided into 2 clusters

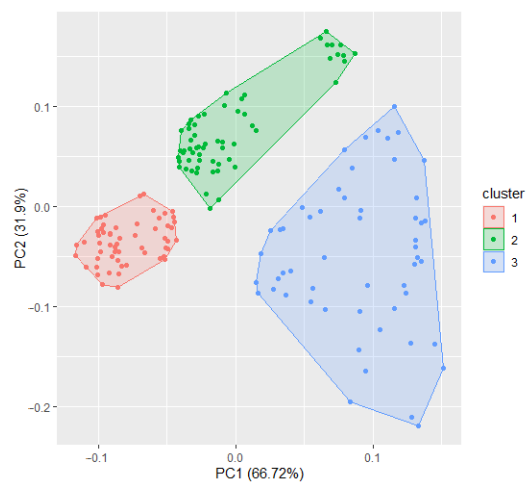


Figure 5. Data is divided into 3 clusters

Table 3. Cluster means (scaled database) (source: research data)

Variables k-group	AMZ	CONEC	LAT	LON
1	-1.4540741	-0.8519500	-1.13834163	0.7161541
2	-0.6654237	0.1729505	-0.00770837	-1.0135949
3	-0.6654237	0.5995695	1.031958891	0.3352697



Figure 6. Azul Conecta's Cessna Grand Caravan (PT-MEJ) with the Brazilian flag livery (source: Azul Airlines, 2022)

Azul Conecta is found to be the main operator in the Brazilian context under the type of operation focused on this study. Other companies also had regular flight service during the coverage period of the dataset, such as Aerosol and Abaeté Linhas Aéreas, their service is either limited to only one location, in the case of the latter, or operated during a short period of time, in the case of the former.

5. Results

In this section, an analysis of characteristics of the served airports, including population, distance, connectivity, runway length, surface, and operational capabilities, is conducted using the previously obtained clusters. To allow analysis of the division of service between lifeline and economically driven routes mentioned in Section 3, the results will be presented for the entire group of airports with service and for a subgroup consisting only of locations outside the Amazon Area (ex-AMZ).

A positive relation between population and passenger demand is backed by the literature (Boguslaski et al., 2004; Müller et al., 2012), commonly with this being identified as the most significant factor for air transport services in the literature. In Figure 7, the population of the served cities is shown.

As shown in Figure 7, lifeline routes appear to prioritize service in areas with lower expected demand, rather than focusing on developing other infrastructure in sequence.

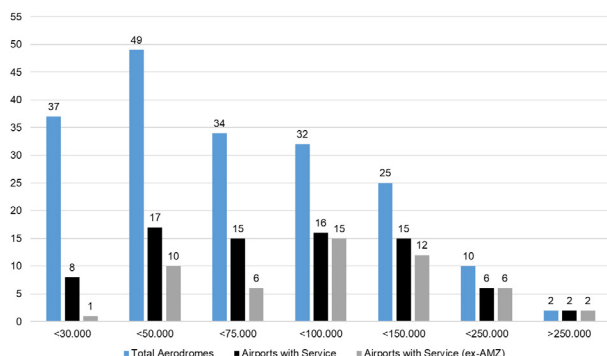


Figure 7. Population in cities with active aerodromes

This is because most flights within the Amazon Area connect cities with fewer than 75,000 residents, including 83% (5 out of 6) in the lower 30,000-resident range. There is no service to a city larger than 150,000 inhabitants in the Amazon Area.

Meanwhile, other markets primarily aim to establish commercial services, considering the demand factors, and a positive relationship with the population is found. From the 75,000 inhabitants' threshold, at least half of the airports serving those locations have an active service at the moment of the study, while the proportion to the airports serving the lower population group is only 21.6%.

The "distance to state capital" factor is used because the services in the case study analyzed are, with few exceptions, limited to the state level, connecting small interior locations to the state capital. Therefore, it can be expected that the greater the distance, the more attractive the air transport option will be, as the difference in travel time between air and road increases. Conversely, cities near the state's capital tend to be less appealing, as procedures related to air travel, such as arriving at the airport about an hour early, passenger check-in, and baggage check, account for a larger share of the total travel time. The distance is calculated using data from ANAC's aerodrome database for latitude and longitude, considering a flat plane, and by the calculation of the square root of the squared differences in x and y. The values obtained are shown in Figure 8.

As shown in Figure 8, the distances range from 34 to 1,164 kilometers in the study sample. Due to geographical features, all airports more than 660 km away are located within the large-area states in the Amazon Region (Amazonas, Pará, and Mato Grosso). The average distance across the entire dataset is 353 kilometers. When filtered for airports with C208 service, most flights are between 121 and 480 kilometers, accounting for 76% of flights by distance.

The relatively low speed of C208 aircraft, compared to regional turboprops or jets, combined with the lack of a lavatory in this type of aircraft, may also discourage airlines from deploying it on longer-distance passenger services.

The connectivity values, which measure the number of road axes connecting the airport in the selected dataset,

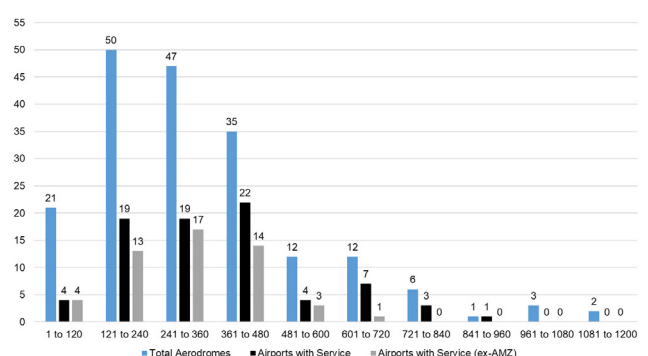


Figure 8. Number of aerodromes per distance to the capital interval (kilometers)

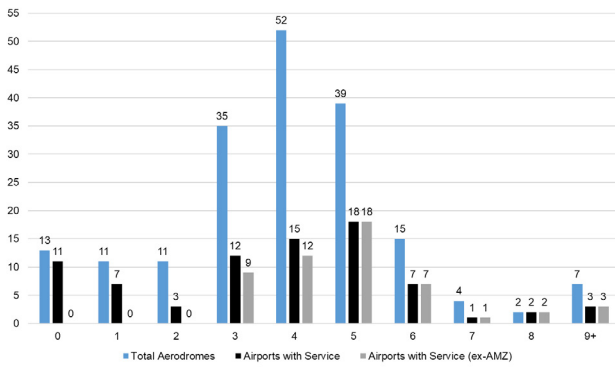


Figure 9. Number of aerodromes per CONEC variable value

range from 0 to 9, with an average of 3.6. As shown in Figure 9, most aerodromes have values between 3 and 5. However, a more uniform distribution emerges when considering only airports that receive flight services.

All airports with a value of 0 in Figure 9 are in Amazonas and Pará, and no airport served in the Amazon Area has a value greater than or equal to 5 for this variable. The relatively high percentage of airports receiving flight service among the sample with values of 0 or 1 also reinforces the lifeline characteristics of the service within those isolated areas, with a substantial share of locations connected through air transport. Generally, airports in the Amazon region that receive flights have no or poor road connectivity, serving as the main connection between the city and the rest of the country.

On the other hand, all those with values of 7 or higher are in Paraná or Rio Grande do Sul, more developed and populated states with greater road connectivity, where most cities have easy access to state capitals or secondary cities within their region. The findings of this variable are directly related to those observed by Silva et al. (2022).

Infrastructure is also lacking, particularly in terms of runway surfaces and operational capabilities. Runway length and width, as shown in Figure 10, are associated with the airport classification code, which determines the categories of aircraft it can accommodate. These factors are related to the service capacity of the receiving aircraft, which is

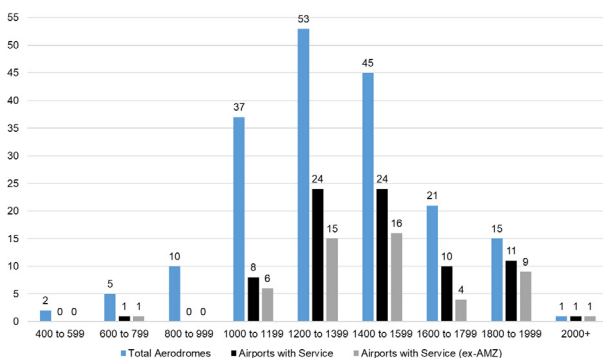


Figure 10. Number of aerodromes per runway length interval (meters)

the focus of this study, or even larger aircraft. This could influence an airline’s decision to ensure service continuity, accommodate increased local demand, or use an operationally cheaper aircraft to test the demand response, especially in the case of Azul Conecta, a subsidiary of an airline that adopts the strategy of operating a diversified fleet of aircraft to better serve different market demands.

Figure 10 shows that aerodromes in this study have runway lengths ranging from 403 meters to 1,897 meters, with most between 800 and 1,600 meters. This range indicates different possibilities for aircraft operations, although other factors, such as runway width, are also considered for a more detailed analysis. For example, an ATR 72 aircraft at full capacity needs around 1,400 meters of runway to take off, while the same values also enable the operation of jet-powered airliners, although with certain limitations on usable payload.

The runway surface can also influence operations. While an aircraft like the Cessna Grand Caravan can operate on surfaces such as earth or grass, companies might prefer to ensure safer and more consistent operations on asphalt or concrete. This is represented as a dummy variable with a value of “1” for runways made of asphalt or concrete and “0” for other types. Figure 11 shows that 158 out of 189 (83.6%) aerodromes analyzed have paved runways, either asphalt or concrete.

The existence of flight service with paved runways is clearly visible in Figure 11: only 2.5% of airports with commercial operations have non-paved runways, none of which are outside the Amazon Area.

The available infrastructure is also affected by factors related to the operation type and fuel supply. An airport that handles IFR (Instrument Flight Rules) night flights provides operators with much greater flexibility than one limited to VFR (Visual Flight Rules) daytime operations. This factor will be represented as a dummy variable, with “0” indicating airports that can only handle daytime VFR flights, and “1” for any other operational conditions (Nighttime VFR and/or daytime/nighttime IFR). The classification of the aerodromes’ scope used in this study is shown in Figure 12.

Figure 12 shows that 133 out of 189 (70.4%) aerodromes analyzed are limited to only VFR Daytime Flights,

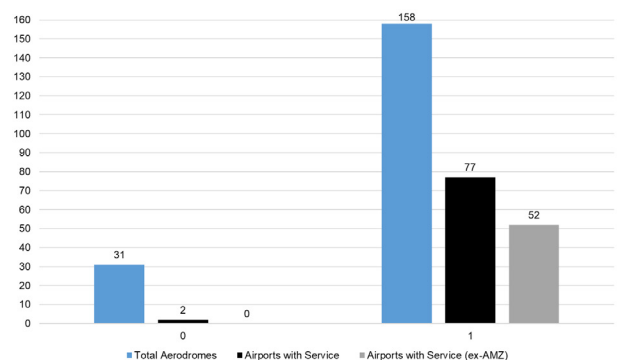


Figure 11. Number of aerodromes with paved (concrete or asphalt) runways

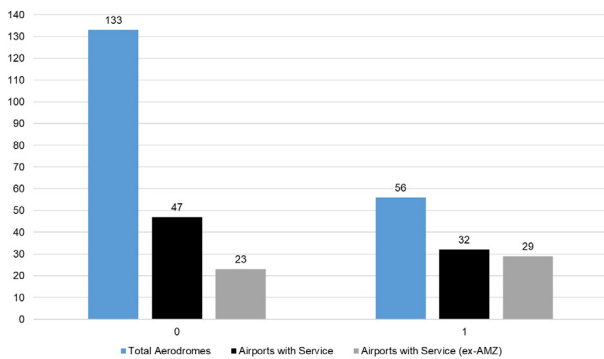


Figure 12. Number of aerodromes capable of receiving only VFR Daytime flights or others

which restricts their operational flexibility, although most flights operated by Azul Conecta occur during daylight hours. In contrast, all airports serving regular commercial flights (excluded from the dataset) have IFR capabilities.

The data reveals patterns in small airports using low-seat capacity aircraft: city populations typically range from 30,000 to 150,000 residents; road connection features vary depending on whether the aerodrome is in the Amazon area or not; distance to the origin city usually falls between 120 and 480 kilometers; runway length generally ranges from 1,200 to 1,600 meters; runways are paved with either concrete or asphalt; there is a trend toward aerodromes capable of supporting IFR and/or night flights.

6. Conclusions

Aerodrome characteristics for the commercial air service market niche served by small aircraft vary mainly by route type. In the initial analysis of the data, some patterns emerge for the airports served. However, different types of routes (lifeline or economic) appear to influence specific variables, such as connectivity.

Lifeline service within the Amazon Area has unique features and differs from what is seen in other parts of Brazil, with isolation or lack of connectivity being positively associated with the presence of flight service. The only 2 of 79 locations with a non-paved surface runway are also located at the states of Amazonas and Pará.

Within the Amazon region, potential investments in airport infrastructure should primarily address an eventual lack of connectivity, with population numbers a secondary factor. Infrastructure characteristics, such as runway surface and navigational aids, are relevant and favorable to commercial operations in any context. However, the limited demand originating from those isolated locations should discourage greater investment expenditure, unless greater operational flexibility for other purposes, such as national defense, is desired.

Outside the Amazon Area, a more conventional relationship between flight service and variables such as population is observed. Road connectivity tends to be correlated with the city's relative importance in the region, thus

not diminishing its flight service potential. At the same time, proximity to the state capital should be considered, as time-consuming activities related to a flight service (check-in, luggage dispatching, boarding, etc.) may not offset the lower travel time benefit.

The lower cost of flight services and the availability of incentives may also influence these variables, leading to differences in outcomes seen at airports that handle higher passenger volumes and aircraft with larger capacities. Future models should be able to identify key factors for offering thin-demand routes and assess the impact of subsidies on airlines operating in this niche market.

This research is not exhaustive. It primarily presents a specific case study within the Brazilian context. Airline fleet and market strategies, along with external factors such as government incentives, influence service levels at small airports and may result in unique characteristics, as seen in the case study discussed.

Furthermore, the methodology does not address other important themes identified in the literature review, such as the coexistence of subsidies and thin-demand routes, as well as the challenges of the viable operation and maintenance of smaller structures. Future exploration of these themes will offer a more comprehensive view of the problem and a clearer understanding of this niche in air transport services.

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Author contributions

PTMR and MC conceived the study and were responsible for its design and data analysis development. PTMR was responsible for data collection and analysis. PTMR and MC were responsible for data interpretation. PTMR wrote the first draft of the article. MC, MXG, AVMO, and VRRRC were responsible for supervision, formal analysis, and approval of the paper. All the authors contribute to the final version of this paper.

Disclosure statement

The authors declare that they have no conflicts of interest with any other parties, whether financial, professional, or personal.

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